



Measurement of W and Z Production Cross Sections and Ratio in Muon Channel with 194 pb^{-1}

The CDF Collaboration¹

Abstract

We present a new updated measurement of the ratio of inclusive W and Z boson cross sections in proton-antiproton collisions at 1.96 TeV at the Fermilab Tevatron, using high- P_T muons in the CDF detector. Our measurement yields:

$$\sigma(p\bar{p} \rightarrow W)BR(W \rightarrow \mu\nu) = 2.786^{+0.065}_{-0.055}(\text{syst}) \pm 0.012(\text{stat}) \pm 0.166(\text{lum}) \text{ nb},$$

$$\sigma(p\bar{p} \rightarrow Z)BR(Z \rightarrow \mu^+\mu^-) = 253.1^{+8.3}_{-6.4}(\text{syst}) \pm 4.2(\text{stat}) \pm 15.2(\text{lum}) \text{ pb},$$

$$R = 11.02^{+0.17}_{-0.14}(\text{syst}) \pm 0.18(\text{stat}).$$

A comparison with theoretical predictions allows an indirect value for the W leptonic branching ratio:

$$BR(W \rightarrow \mu\nu) = 11.01^{+0.17}_{-0.14}(\text{syst}) \pm 0.18(\text{stat}) \pm 0.05(\text{ext}) \text{ } \%$$

Using the Standard Model prediction for $\Gamma(W \rightarrow \mu\nu)$ we extract the total width of the W boson:

$$\Gamma(W) = 2056^{+26}_{-32}(\text{syst}) \pm 34(\text{stat}) \pm 10(\text{ext}) \text{ MeV}.$$

We discuss the significance of the ratio measurement in light of existing information on W and Z production and decay.

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1 Introduction

After the great success of the Fermilab Tevatron in Run I (1992-1995), the CDF collaboration is eagerly pursuing an exhaustive program of electroweak physics during Run II (2002 - present). In addition to improvements in the detector acceptance and performance resulting from the upgraded CDF detector, we observe gains in the event yields arising from the increased center-of-mass energy. The $p\bar{p}$ collisions produced at the Tevatron have gone from $\sqrt{s} = 1.8$ TeV in Run I to $\sqrt{s} = 1.96$ TeV in Run II, and thus provide us with an increase of about 10% in the production cross sections of W and Z^0 bosons.

Measurements of the weak vector boson production cross sections $\sigma(p\bar{p} \rightarrow W \rightarrow \mu\nu)$ and $\sigma(p\bar{p} \rightarrow \gamma^*/Z^0 \rightarrow \mu^+\mu^-)$ provide important tests of the consistency of the Standard Model parameters as well as tests of QCD. The W and Z^0 bosons have become the *standard candles* of collider experiments and consequently, these measurements enable us to acquire a good understanding of our detector efficiencies, backgrounds and luminosity. Using the data sample collected with the CDF detector between March 2002 and September 2003, representing 194 pb^{-1} , we make new measurements of the W and γ^*/Z^0 production cross sections in the muon decay channels. The ratio of W and Z^0 cross sections eliminate a number of uncertainties and provides a high precision measurement of the W width. This is an update to an earlier analysis using a smaller data sample of 72 pb^{-1} .

2 W and γ^*/Z^0 Production Cross Sections

The measured cross section can be expressed as

$$\sigma \cdot BR = \frac{N(1-b)}{A\epsilon \int \mathcal{L} dt}, \quad (1)$$

where N is the number of observed events, b is the estimated fraction of background events, A is the kinematic and geometric acceptance, ϵ is the total efficiency and $\int \mathcal{L} dt$ is the integrated luminosity of the data sample.

We select $W \rightarrow \mu\nu$ decays by requiring high momentum muons ($P_T > 20\text{ GeV}/c$) in the central region of the detector ($|\eta| \leq 0.6$) and large missing energy due to the undetected neutrino ($\cancel{E}_T > 20$). All event quantities are measured in the transverse plane since the z component of the neutrino momentum is unmeasured. $Z^0 \rightarrow \mu^+\mu^-$ decays are identified as a central muon and a second oppositely-charged central track with an invariant mass around the Z^0 mass. Figure 1 shows the \cancel{E}_T distribution for candidate $W \rightarrow \mu\nu$ events (cut indicated by the line). Figure 2 shows the transverse mass distribution for candidate $W \rightarrow \mu\nu$ events, from which we will directly measure M_W and $\Gamma(W)$ in the future. Figure 3 shows the invariant mass distribution of the dimuon pairs for $Z^0 \rightarrow \mu^+\mu^-$ events. The agreement between the data and the expectation is excellent.

The sources of background in the $W \rightarrow \mu\nu$ events include $Z^0 \rightarrow \mu^+\mu^-$ events where one of the muons is missed by the detector, $W \rightarrow \tau\nu$ when the τ decays in muon, QCD jets events where jet fakes a muon, and cosmic rays. The total background is estimated to be $\sim 9.45\%$ with the dominant background contribution coming from $Z^0 \rightarrow \mu^+\mu^+$ and $W \rightarrow \tau\nu$ events. The $Z^0 \rightarrow \mu^+\mu^+$ samples are quite clean; the total background is estimated to be $< 0.4\%$. The sources of background in the Z^0 channels include QCD jets, $Z^0 \rightarrow \tau^+\tau^+$ and cosmic rays.

We determine the kinematic and geometric acceptance, A , using a Monte Carlo simulation. The total efficiency, ϵ , encompasses several different efficiencies: triggering on and reconstructing the lepton, the selection criteria used to identify the muons, and event topology selection used to select the signal events and minimize the backgrounds in the samples. The majority of these efficiencies are directly measured from the data.

The input parameters of the W and γ^*/Z^0 cross section measurements are summarized in Table 1. Using this parameters in Equation 1, we obtain

$$\sigma(p\bar{p} \rightarrow W)BR(W \rightarrow \mu\nu) = 2.786_{-0.055}^{+0.065}(\text{syst}) \pm 0.012(\text{stat}) \pm 0.166(\text{lum}) \text{ nb},$$

$$\sigma(p\bar{p} \rightarrow Z)BR(Z \rightarrow \mu^+\mu^-) = 253.1_{-6.4}^{+8.3}(\text{syst}) \pm 4.2(\text{stat}) \pm 15.2(\text{lum}) \text{ pb}.$$

The systematic uncertainty is dominated by dependence of the acceptance on the Parton Distribution Functions (PDFs) [1]. Additionally, since many of the efficiencies are measured from the data, they are limited by the statistics of our Z sample, and hence also contribute to the total systematic uncertainty. The luminosity uncertainty, quoted separately, comes from the acceptance of the luminosity monitor and from the estimate of the total $p\bar{p}$ cross section [2]. These cross section measurements agree well with the NNLO theoretical calculation [3], as can be seen in Figure 4.

The ratio of the total W and Z^0 cross sections, R , is also an important test of the Standard Model. A precision measurement of this ratio tests the branching ratio $\Gamma(W \rightarrow \mu\nu)/\Gamma(W)$ in addition to $\Gamma(W)$. $\Gamma(W)$ is sensitive to new physics and could be affected by new decay modes of the W boson. While the parameters of the Z^0 boson have been well-studied, the properties of the charged current carrier, the W , are known with less precision. A new high mass resonance which decays to W or Z^0 bosons would result in a change in their production cross sections. The ratio of cross sections is expressed as

$$R = \frac{\sigma(p\bar{p} \rightarrow W)}{\sigma(p\bar{p} \rightarrow Z)} \frac{\Gamma(W \rightarrow \mu\nu)}{\Gamma(Z \rightarrow \mu\mu)} \frac{\Gamma(Z)}{\Gamma(W)}. \quad (2)$$

Many uncertainties cancel in R , which dominate in the individual cross section measurements, such as the uncertainty on the luminosity estimate. Table 1 shows the input parameters used in the ratio calculation. Our measurement yields

$$R = 11.02_{-0.14}^{+0.17}(\text{syst}) \pm 0.18(\text{stat}).$$

This result compares well with the NNLO theoretical calculation of $R = 10.67 \pm 0.15$ [3].

The value of R can be used to extract $BR(W \rightarrow \mu\nu)$ and $\Gamma(W)$, using the measured value of $\Gamma(Z^0 \rightarrow \mu^+\mu^-)/\Gamma(Z) = 0.033658 \pm 0.000023$ at the Z pole [4] and the theory values of $\Gamma(W \rightarrow \mu\nu) = 226.4 \pm 0.3$ MeV and $\sigma(p\bar{p} \rightarrow W)/\sigma(p\bar{p} \rightarrow Z) = 3.3677 \pm 0.0058$ [3]. Extracting the leptonic branching ratio for W decays, we find

$$BR(W \rightarrow \mu\nu) = 11.01^{+0.17}_{-0.14}(\text{syst}) \pm 0.18(\text{stat}) \pm 0.05(\text{ext}) \, \%.$$

which compares well with the world average value of 0.1068 ± 0.0012 . Now extracting the total width of the W boson, we find

$$\Gamma(W) = 2056^{+26}_{-32}(\text{syst}) \pm 34(\text{stat}) \pm 10(\text{ext}) \text{ MeV}.$$

This value agrees with the PDG fit of 2118 ± 42 MeV [4] and the SM prediction of 2092.1 ± 25 MeV [5]. In Figure 5 our measurement of $\Gamma(W)$ is compared with other measurements in literature [4].

3 Conclusions

We have preliminary measurements of the inclusive W and Z^0 boson production cross sections times leptonic branching ratios in muon channel in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV using CDF Run II data. We measure the ratio of these cross sections times branching ratio, R . From R we extract W leptonic branching ratio and the total width of the W boson, all consistent with the Standard Model predictions.

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Parameter	W	Z	Ratio R
Integrated Luminosity	$\int L dt$ 193.5 \pm 11.6 pb $^{-1}$	$\int L dt$ 193.5 \pm 11.6 pb $^{-1}$	
Number Of Candidates	N_W 57,109	N_Z 3,568	$\frac{N_W}{N_Z}$ 16.006
Background Fraction	b_W 0.0949 \pm 0.0045	b_Z 0.0036 \pm 0.0019	$\frac{1-b_W}{1-b_Z}$ 0.908 \pm 0.005
Acceptance	A_W 0.1451 $^{+0.0020}_{-0.0024}$	A_Z 0.1153 $^{+0.0021}_{-0.0026}$	$\frac{A_Z}{A_W}$ 0.7949 $^{+0.0068}_{-0.0076}$
Efficiency	ϵ_W 0.661 $^{+0.009}_{-0.010}$	ϵ_Z 0.633 $^{+0.011}_{-0.015}$	$\frac{\epsilon_Z}{\epsilon_W}$ 0.957 $^{+0.007}_{-0.011}$

Table 1: Measured input parameters for the cross section and ratio calculations.

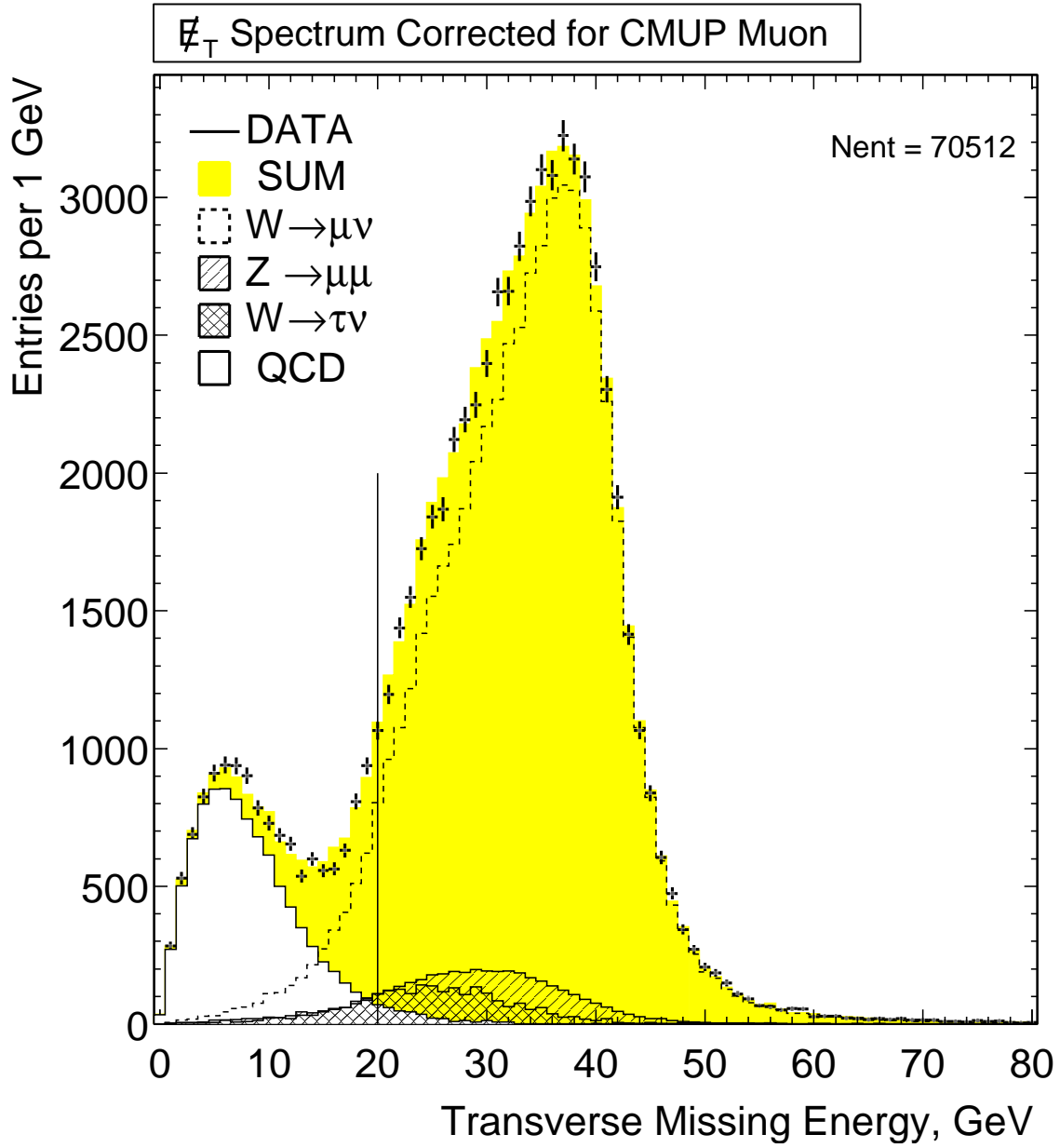


Figure 1: \cancel{E}_T in data and Monte Carlo for $W \rightarrow \mu\nu$ candidate events.

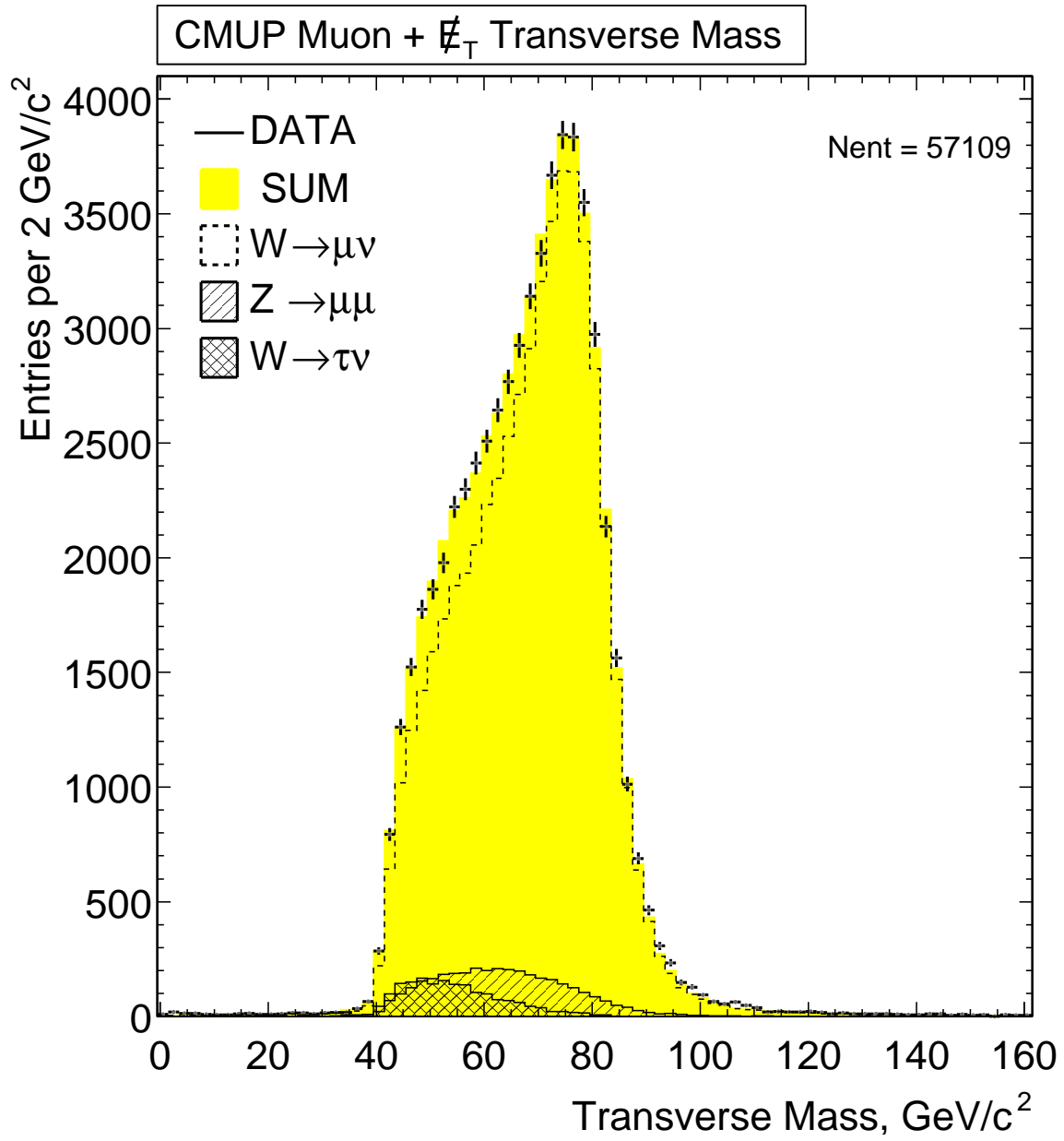


Figure 2: The transverse mass spectrum in data and simulation for $W \rightarrow \mu\nu$ events.

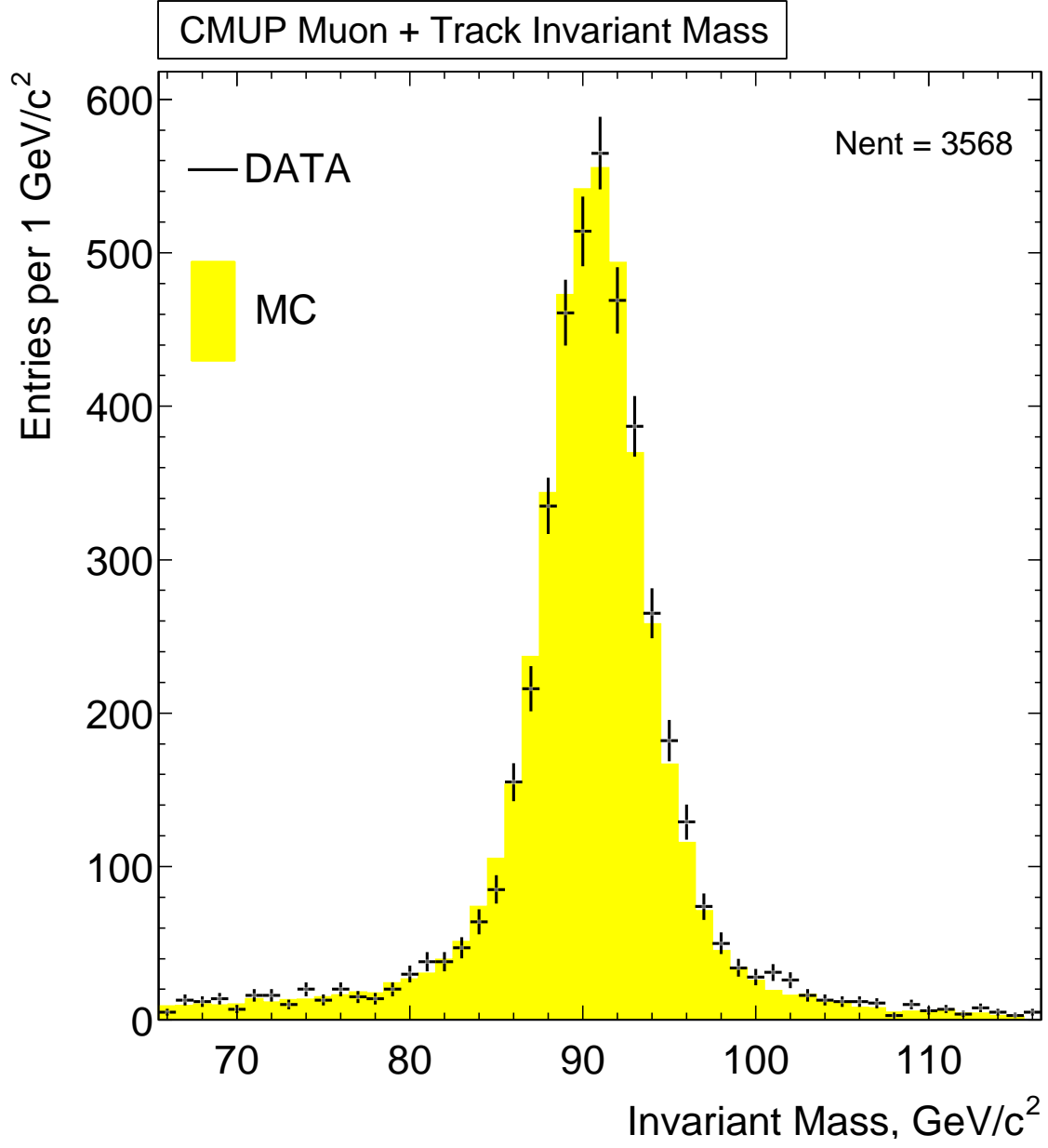


Figure 3: Dimuon invariant mass $M_{\mu\mu}$ distribution in data and simulation for $Z \rightarrow \mu^+\mu^-$ candidate events.

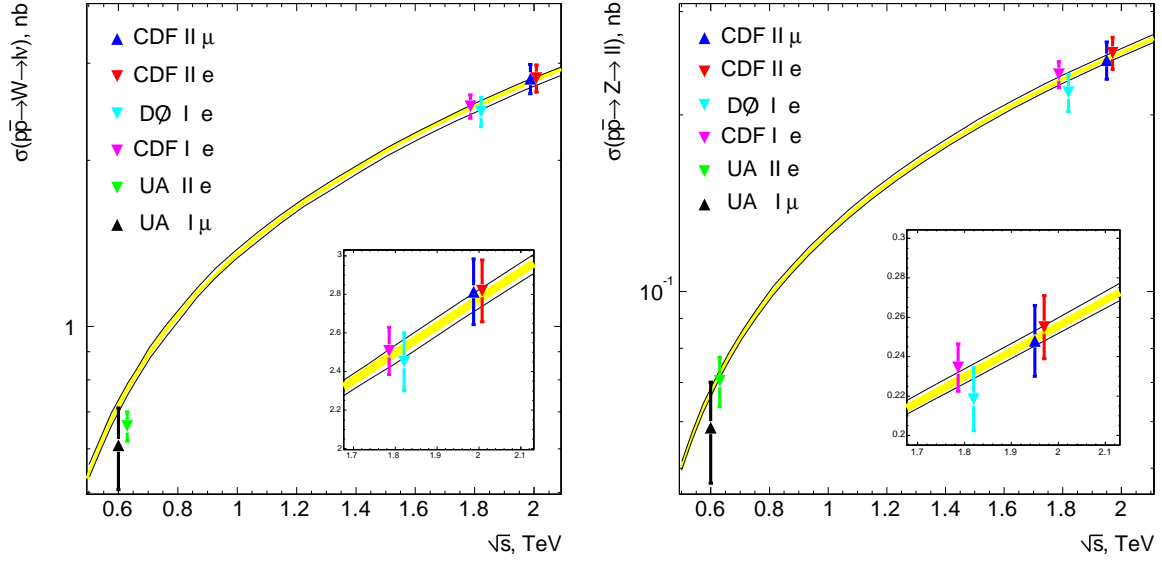


Figure 4: The measurements of W and Z production cross section in leptons.

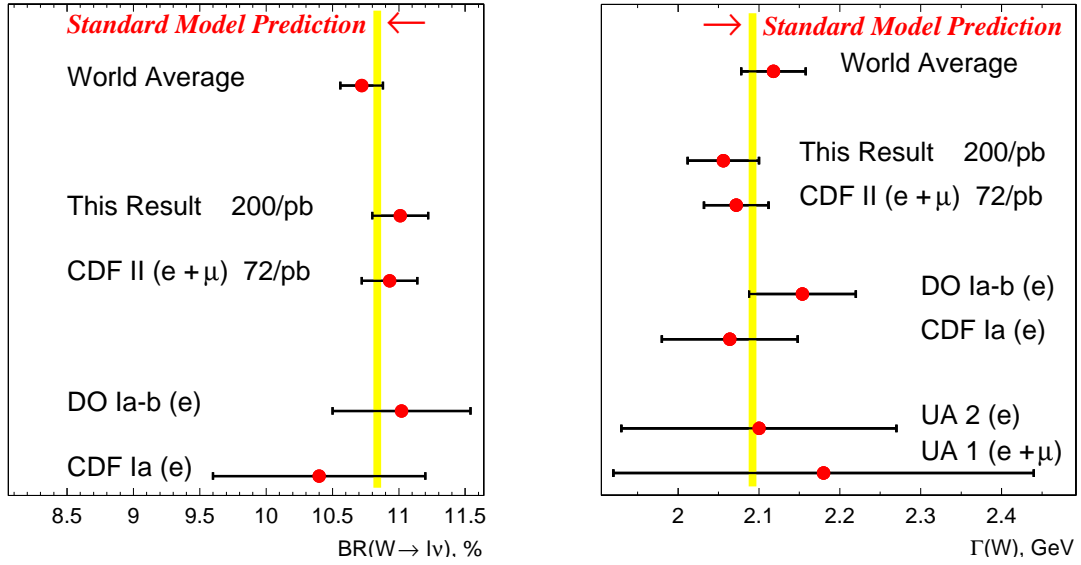


Figure 5: Comparison of our result for $BR(W \rightarrow \ell\nu)$ and $\Gamma(W)$ with those from the other measurements and the Standard Model expectation.